TEMPERATURE CONTROL OF A NEONATE INTENSIVE CARE UNIT USING KALMAN FILTER

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ABSTRACT

This work proposes using a state observer structure and a Kalman filter for controlling a dead time system. The practical implementation for the proposed structure is done in a thermal system, corresponding to a temperature control of a neonate intensive care unit. The results obtained are compared to different controllers, as state space controller and a Smith predictor.

Keywords: Kalman, Smith, observer, predictive.

INTRODUCTION

The neonate heat body production is provided by biochemist processes that sustain the life. The necessary neonate produced heat quantity is between 1.5 and 2 W/Kg (body mass). The healthy neonates are able to products additional heat between 4.5 and 5 W/Kg whose objective is maintain a reserve and protection in emergence situations as an anti-infection action (Costa, 2009).

Neonate intensive care units are used for neonate treatment in adverse situations reaction problems (Uchoa et al, 2010), providing to neonate a thermally neutral environment, owing by temperature and relative air humidity control, maintaining those variables in acceptable levels, resulting in normal neonate body temperature, metabolic rate lower, and a minimal body heat possible.

The intensive care unit, maintain the neonate in a controlled environment, being therefore, favorable to its growing, development, disease resistance and to its survival. These intensive care units are constructed according to NBR IEC 601-2-19 technical norm that determine the minimal necessary requirement for minimizing risks to patient and users, as well as suggest tests whereby it can evaluate the compliance to that requirement. It’s necessary a temperature and relative air humidity efficient control systems.

The use of state space controllers has efficient results when the precise mathematic model is available; besides the states haven’t big dimension. In this sense, the controller is designed to system satisfy some pre-defined parameters, as maximum overshoot and settling time, that are warranted by pole system allocation, controlled by state feedback. However, there are systems whose states are not available; being necessary estimated them using an observer which can be designed separated of controller.

This article proposes using a state feedback controller to be applied for controlling the neonate intensive care unit temperature, where the used observer is a Kalman filter.

The Kalman filter (Kalman, 1960) is a recursive predictive filter based on state space recursive techniques for estimate the state of a dynamic system. This system can be disturbed by noise (white noise). To improve the estimate state the Kalman filter uses mesurements that
are related to the state but disturbed as well. Thus Kalman filter consists of two steps: prediction, where state is predicted with dynamic model, and correction, that uses an observation model for correcting, so the KF is an optimal estimator (Haykin, 2001).

MATHEMATIC MODEL

The mathematic model used was obtained by experimental results, according to identification methods. The tests involved the input applications of 100% after 10 minutes of initialization, and 30 minutes after the input was reduced to 10% through the end of one hour in test. It was used a sample time of 24 seconds. The equation (1) shows the first order model obtained.

\[ P(s) = \frac{0.179 e^{-2.89s}}{465.8s^2 + 88.16s + 1} \] (1)

The system model representation in state space is showed in equations (2) and (3).

\[
\begin{bmatrix}
\dot{x} \\
y
\end{bmatrix} =
\begin{bmatrix}
-0.1174 & -0.0378 \\
0.0313 & 0
\end{bmatrix}\begin{bmatrix}
x \\
u
\end{bmatrix} + 
\begin{bmatrix}
0,1250 \\
0
\end{bmatrix}w
\]

(2)

\[
y = \begin{bmatrix} 0 & 0.0722 \end{bmatrix}x + v
\]

(3)

Where \( w \) is the process disturbance and \( v \) is measurement noise, whose correlation matrices are respectively \( Q_o \) and \( R_o \) (considered design parameters).

The figure 1 shows the neonate unit care used. This unit belongs to Automation and Robotic Lab, on Electrical Engineering Department – Universidade Federal do Ceará.

Fig. 1 - Neonate unit

FEEDBACK FOR CONTROL STATES USING KALMAN FILTER

From the representation of the system in state space, the control is to feed back the state vector to which a matrix \( K \) is applied, called feedback gain calculated by the poles corresponding to the controlled system design parameters such as overshoot and time stabilizing respectively 10% and the 0.1667 seconds.

Thus, the controlled system is given by the equation:

\[ \dot{x} = (A - BK)x + Br \\
y = Cx 
\]

(5)

The state vector is estimated, since it is not available and so a state estimator is needed, which in this case is a Kalman filter. The choice of this observer is because of its ability to reduce the disturbing effects on the process and measurement noise in the calculation of the estimate, which characterizes it as a great observer. The dynamic filter is described by
where $L$ is the Kalman gain matrix filter obtained as follows:

$$L = SC^T R_o^{-1}$$  \hspace{1cm} (7)

The $S$ matrix is positive semidefinite and is the solution of the Riccati equation:

$$AS + SA^T - SC^T R_o^{-1} CS = -Q_o$$  \hspace{1cm} (8)

![Block diagram of the controller and observer](image)

**RESULTS**

Figure 3 shows the temperature output obtained through simulation where there is the output follows the reference value with no apparent overshoot, which is also shown a curve which represents the control signal applied.

![Neonate Unit Temperature](image)

The results obtained with the proposed structure is shown in Fig. 4. This figure shows the temperature output and the control signal applied to neonate unit where there is a good approximation between the measured temperature and estimated by the filter, even in the presence of the very system disturbances and noises in the actual measurement. We also observe a good agreement between the graphs obtained in simulation and the corresponding results in experimental test.

![Control Signal](image)
CONCLUSION
The results were satisfactory in the incubator temperature control. This experiment shows the reference and estimated output are closer. The correlation index was around 0.97 for this case. The system reached the reference on time and overshoot within 10% depending on the design parameters, after following the reference value. The filter was efficient because the state vector estimates is essential to the proper functioning presented by the controller.

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REFERENCES